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(71) 出願人 (米国を除く全ての指定国について): 東京エレクトロン株式会社 (TOKYO ELECTRON LIMITED) [JP/JP]; 〒107-8481 東京都 港区 赤坂五丁目3番6号 Tokyo (JP).

(72) 発明者; および
(75) 発明者/出願人 (米国についてのみ): 石井 信雄 (ISHII,Nobuo) [JP/JP]; 〒660-0891 兵庫県 尼崎市 扶桑町1-8 東京エレクトロン株式会社内 Hyogo (JP).

(74) 代理人: 深見 久郎, 外(FUKAMI,Hisao et al.); 〒530-0054 大阪府 大阪市 北区南森町2丁目1番29号 三井住友銀行南森町ビル 深見特許事務所 Osaka (JP).

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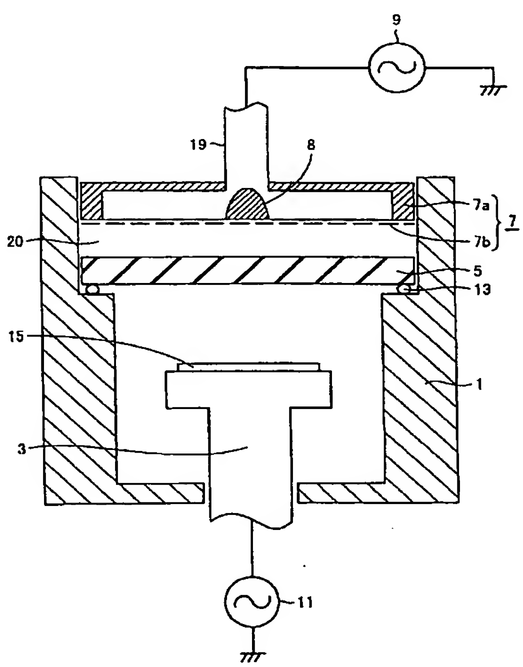
(54) Title: PLASMA PROCESSING SYSTEM

(54) 発明の名称: プラズマ処理装置



(57) Abstract: An antenna section (7) comprises a metallic radial waveguide (7a) and a slot antenna (7b) being connected to the lower end of a waveguide (19). A top plate (5) is arranged at the upper part of a chamber (1). An air layer (20) is formed between the antenna section (7) and the top plate (5). One half of the difference between the inside diameter B of a region where the top plate (5) and the antenna section (7) are located and the inside diameter A of the radial waveguide (7a) is set equal to a natural number times or 0 times of one half of the wavelength λ_g of a microwave based on the combined permittivity of the permittivity of the atmosphere (air layer (20)) in the region where the top plate (5) and the antenna section (7) are located and that of the top plate (5). Furthermore, the inside diameter C of the chamber (1) is set equal to or shorter than the inside diameter A of the radial waveguide (7a). With such an arrangement, plasma density can be made uniform by controlling an electromagnetic field for forming a plasma generating region (17).

(57) 要約: アンテナ部（７）は、導波管（１９）の下端に接続される金属製のラジアル導波路（７ａ）とスロットアンテナ（７ｂ）を備えている。チャンバ（１）の上部には天板（５）が配設されている。アンテナ部（７）と天板（５）との間には空気の層（２０）が形成されている。天板（５）およびアンテナ部（７）が位置する領域の内径Ｂとラジアル導波路（７ａ）の内径Ａとの差の半分の長さが、天板（５）およびアンテナ部（７）が位置する領域における大気（空気の層（２０））の誘電率と天板（５）の誘電率との合成誘電率に基づくマイクロ波の波長λgの半分の長さの自然数倍または０倍となっている。さらに、チャンバ（１）の内径Ｃはラジアル導波路（７ａ）の内径Ａと同じかそれよりも短く設定されている。これにより、プラズマ生成領域（１７）を形成するための電磁界を制御することによって、プラズマ密度を均一にすることができる。

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DESCRIPTION

Plasma Processing Apparatus

Technical Field

The present invention relates to a plasma processing apparatus, and particularly to a plasma processing apparatus effecting predetermined processing on a substrate by using a plasma production region, which is formed by supplying microwaves into a chamber.

Background Art

In recent years, semiconductor devices having higher packaging densities and smaller sizes have been developed. For such structures, plasma processing apparatuses effecting processing such as film deposition, etching and ashing are used. In particular, a microwave plasma processing apparatus, which uses microwaves for producing plasma, can stably produces plasma under a relatively low pressure of about 0.1 to 10 Pa, i.e., under high vacuum conditions. Therefore, attention has been given to a microwave plasma processing apparatus using a microwave of a frequency, e.g., of 2.45 GHz.

An example of the conventional plasma processing apparatus will now be described. Referring to Fig. 6, a plasma processing apparatus has a chamber 101, in which a predetermined process is performed on a substrate introduced therein, a high-frequency power supply 109 for producing a microwave, a waveguide pipe 119 for leading the microwave to the plasma processing apparatus, and an antenna portion 107 for radiating the microwave into chamber 101.

Antenna portion 107 includes a radial waveguide 107a, which is made of metal and is connected to a lower end of waveguide pipe 119, and a disk-like slot antenna 107b covering an opening at a lower end of radial waveguide 107a. A bump 108 is arranged at a position opposed to waveguide pipe 119 above slot antenna 107b for

adjusting an impedance. An atmosphere is present within waveguide 107a.

Slot antenna 107b is formed of, e.g., a copper plate having a thickness from 0.1 to several millimeters. Slot antenna 107b is provided with a plurality of slots or openings for radiating the microwave into chamber 101.

A top plate 105 forming a part of a wall of chamber 101 is arranged in an upper portion of chamber 101. Top plate 105 is formed of a dielectric material such as quartz. A sealing member 113 such as an O-ring is arranged between top plate 105 and the wall of chamber 101. Antenna portion 107 is arranged above top plate 105 with a space therebetween, and an air layer 120 is formed between antenna portion 107 and top plate 105.

In chamber 101, a susceptor 103 is arranged for holding substrate 115. Susceptor 103 is connected to a high-frequency power supply 111 for bias. A vacuum pump (not shown) is connected to chamber 101 for discharging a gas from chamber 101.

According to the above plasma device, the vacuum pump discharges a gas from chamber 101, and a gas such as an argon gas is supplied into chamber 101 for producing plasma under a pressure in a predetermined range.

A microwave in a TE11 mode produced by high-frequency power supply 109 is rotated by a circular polarization converter (not shown) around an axis of waveguide pipe 119, and is transmitted through waveguide pipe 119 to radial waveguide 107a of antenna portion 107.

The microwave transmitted to radial waveguide 107a propagates in a peripheral direction of radial waveguide 107a. The microwave propagating in the peripheral direction generates an electromagnetic field in chamber 101 via slot antenna 107b.

The electromagnetic field generated in chamber 101 dissociates an argon gas so that a plasma production region is formed between substrate 115 and top plate 105, and predetermined plasma processing is performed.

However, the conventional plasma processing apparatus suffers from the following problems. First, an inner peripheral surface of radial waveguide 107a reflects

the microwave, which reached radial waveguide 107a and propagates in the peripheral direction of radial waveguide 107a, so that a first standing wave is formed in radial waveguide 107a.

The microwave radiated from slot antenna 107b is coupled to the microwave, which is reflected and returned by the plasma production region formed in chamber 101, so that a second standing wave is formed in a region, which contains top plate 105 and air layer 120.

The plasma production region within chamber 101 is maintained by the mutual coupling of the first and second standing waves described above. If the mutual coupling of the first and second standing waves is relatively weak, there is a tendency that the second standing wave predominantly contributes to maintenance of the plasma production region.

This second standing wave is liable to vary depending on process conditions such as a pressure in chamber 101, a kind of gas supplied into chamber 101 and an amount of supplied electric power.

As shown in Fig. 6, however, the first standing wave is formed depending on an inner diameter PA of radial waveguide 107a and the mode of the supplied microwave. The second standing wave is formed depending on an inner diameter PB of the region, which contains top plate 105 and air layer 120, and a state of the plasma.

The formation of the second standing wave is also affected by the microwave reflected and returned by the plasma production region, and therefore is significantly affected by the size of the plasma production region. An inner diameter PC of chamber 101 restricts the size of the plasma production region. Therefore, the formation of the second standing wave is also depends on inner diameter PC of chamber 101.

In the conventional plasma processing apparatus, however, inner diameter PA of radial waveguide 107a, inner diameter PB of the region containing top plate 105 and air layer 120, and inner diameter PC of chamber 101 are arbitrarily determined. Therefore, depending on values of diameters PA, PB and PC, the second standing wave

predominantly contributes to the maintenance of the plasma production region.

As described above, the second standing wave is liable to vary depending on the process conditions such as a pressure in chamber 101. Therefore, it is difficult to control the electromagnetic field, which forms the plasma production region, if such unstable second standing wave predominantly contributes to the maintenance of the plasma production region.

If it is difficult to control the electromagnetic field, this results in variations in plasma density within chamber 101. This causes variations in degree or extent of the plasma processing at the substrate surface, and thus causes a problem that variations occur, e.g., in etching rate and film deposition rate.

Disclosure of the Invention

The invention has been developed for overcoming the above problems, and it is an object of the invention to provide a plasma processing apparatus, which controls an electromagnetic field forming a plasma production region, and thereby forms the plasma production region having a uniform plasma density.

According to the invention, a plasma processing apparatus for effecting predetermined processing on a substrate by exposing the substrate to a plasma production region includes a chamber, a top plate portion and an antenna portion. A substrate is introduced into the chamber. The top plate portion is arranged above the substrate introduced in the chamber, and forms a part of a wall of the chamber. The antenna portion supplies a high-frequency electromagnetic field into the chamber to form the plasma production region in a region between the top plate portion and the substrate located in the chamber. The antenna portion includes a radial waveguide having a predetermined inner diameter. The chamber has a predetermined inner diameter in a portion containing the top plate portion and the antenna portion. Assuming that the radial waveguide has the inner diameter of A, the portion containing the top plate portion and the antenna portion has the inner diameter of B, and the high-

frequency electromagnetic field has a wave length of λ_g based on a composite dielectric constant resulting from a dielectric constant of the top plate portion and a dielectric constant of a space of the portion containing the top plate portion and the antenna portion, the following formula is satisfied:

$$(B - A)/2 = (\lambda_g/2) \cdot N$$

where N is zero or a natural number. It is understood that the relationship of the above formula is satisfied even when a size error of about $\lambda_g/10$ occurs.

According to the above structure, each inner diameter is determined to satisfy substantially the above relationship. Therefore, a first standing wave formed in the radial waveguide and a second standing wave formed in the portion containing the top plate portion and the antenna portion have the phases matching with each other, and the mutual coupling of the first and second standing waves becomes stronger than that in a conventional plasma processing apparatus. Thereby, the first standing wave predominantly contributes to the formation and maintenance of the plasma production region. Consequently, the antenna portion can control the formation and maintenance of the plasma production region so that variations in plasma density can be reduced.

A portion of the chamber opposed to the region for producing the plasma has a predetermined inner diameter, which is equal to C, and this predetermined diameter C is preferably set to satisfy a relationship of $(C \leq A)$. It is likewise understood that this relationship is satisfied even when a size error of about $\lambda_g/10$ occurs.

The above structure is preferable for the following reason. If inner diameter C is larger than inner diameter A, the plasma production region formed in the chamber becomes excessively large, and the value of the composite dielectric constant, which results from the dielectric constants of the top plate portion and the space, changes in accordance with the state of the plasma due to such plasma production region so that the foregoing relationship cannot be satisfied, and the strong coupling between the first and second standing waves cannot be achieved.

It is preferable that the top plate portion located in the region containing the

second standing wave specifically includes a dielectric material such as quartz.

Brief Description of the Drawings

Fig. 1 is a cross section of a plasma processing apparatus according to an embodiment of the invention.

Fig. 2 illustrates an operation of the plasma processing apparatus of the embodiment, and particularly shows rotation of a microwave.

Fig. 3 illustrates an operation of the plasma processing apparatus of the embodiment, and particularly shows states of standing waves.

Fig. 4 illustrates an operation of the plasma processing apparatus of the embodiment, and particularly shows the standing wave rotating in a radial waveguide.

Fig. 5 is a cross section of a plasma processing apparatus according to a modification of the embodiment.

Fig. 6 is a cross section of a conventional plasma processing apparatus.

Best Modes for Carrying Out the Invention

A plasma processing apparatus according to an embodiment of the invention will now be described. As shown in Fig. 1, a plasma processing apparatus includes a chamber in which a predetermined process is performed on a substrate 15 introduced therein, a high-frequency power supply 9 for producing a microwave, a waveguide pipe 19 leading the microwave to the plasma processing apparatus, and an antenna portion 7 for radiating the microwave into chamber 1.

Antenna portion 7 includes a radial waveguide 7a, which is made of metal and is connected to a lower end of waveguide pipe 19, and a disk-like slot antenna 7b covering an opening at a lower end of radial waveguide 7a. A bump 8 for adjusting an impedance is arranged above slot antenna 7b, and is opposed to waveguide pipe 19. An atmosphere is present within waveguide 7a.

Slot antenna 7b is formed of a copper plate or the like having a thickness, e.g.,

from 0.1 to several millimeters. Slot antenna 7b is provided with a plurality of slots (openings) for radiating the microwave into chamber 1.

A top plate 5 forming a part of a wall of chamber 1 is arranged above chamber 1. Top plate 5 is made of quartz or the like. A sealing member 13 such as an O-ring is arranged between top plate 5 and the wall of chamber 1. Antenna portion 7 is located above top plate 5 with a space therebetween, and an air layer 20 is formed between antenna portion 7 and top plate 5.

A susceptor 3 holding substrate 15 is arranged in chamber 1. Susceptor 3 is connected to a high-frequency power supply 11 for bias. A vacuum pump (not shown) for discharging a gas from chamber 1 is connected to chamber 1.

In this plasma processing apparatus, half a difference between an inner diameter B of a region, in which top plate 5 and antenna portion 7 are present, and an inner diameter A of radial waveguide 7a is equal to a product of half a wave length λ_g of the microwave, which is based on a composite dielectric constant resulting from a dielectric constant of top plate and a dielectric constant of the atmosphere (air layer 20) in the region containing top plate 5 and antenna portion 7, and zero or a natural number. Thus, the size relationship can be represented by the following formula:

$(B - A)/2 = (\lambda_g/2)\cdot N$ (N: zero or natural number)

Further, an inner diameter C of chamber 1 is shorter than inner diameter A of radial waveguide 7a, or is equal to inner diameter A as will be described later. In the case where N is equal to zero, inner diameter A is substantially equal to inner diameter B. It is understood that the size relationship of the above formula is satisfied even when a size error of about $\lambda_g/10$ occurs.

An operation of the plasma processing apparatus described above will now be described. First, the vacuum pump discharges a gas from chamber 1, and a gas such as argon gas for producing plasma under a pressure of a predetermined range is supplied into chamber 1.

High-frequency power supply 9 produces the microwave of circular polarization

in a TE11 mode. As shown in Fig. 2, the microwave in the TE11 mode is rotated around the axis of waveguide pipe 19 by a circular polarization converter (not shown) arranged in waveguide pipe 19, and thereby is transmitted as a microwave 21, which is rotating in a direction of an arrow Y, through waveguide pipe 19 to radial waveguide 7a.

The microwave transmitted to radial waveguide 7a propagates in a peripheral direction of radial waveguide 7a. The microwave propagating in the peripheral direction generates an electromagnetic field in chamber 1 through slot antenna 7b.

The electromagnetic field produced in chamber 1 ionizes the argon gas to form a plasma production region between substrate 15 and top plate 5 so that a process gas is dissociated, and predetermined plasma processing is effected on substrate 15.

In this processing, as shown in Fig. 3, the microwave propagating in the peripheral direction of radial waveguide 7a is reflected by the inner peripheral surface of radial waveguide 7a so that a first standing wave S1 is formed in radial waveguide 7a.

The microwave radiated from slot antenna 7b is reflected by a plasma production region 17 formed in chamber 1 by the radiated microwave, and the mutual combination of these microwaves, i.e., the radiated microwave and the reflected microwave form a second standing wave S2 in the region containing top plate 5 and antenna portion 7.

In this plasma processing apparatus, since inner diameters A and B as well as the wave length of the microwave satisfy the relationship of the foregoing formula, a standing wave of a wave length, which is substantially N (N: natural number) or zero times larger than the wavelength of $\lambda_g/2$ is formed from second standing wave S2 in a portion L, which corresponds to a length equal to half a difference between inner diameter A and inner diameter B of the region containing top plate 5 and antenna portion 7. For the sake of simplicity, N in Fig. 3 is equal to one so that a standing wave of a wave length of $\lambda_g/2$ is formed.

Further, inner diameter C of chamber 1 is substantially equal to or shorter than inner diameter A of radial waveguide 7a. Therefore, it can be considered that plasma production region 17 formed and maintained in chamber 1 hardly affects the value of the

composite dielectric constant resulting from the dielectric constant of the atmosphere in the region, which contains top plate 5 and air layer 20, and the dielectric constant of top plate 5.

Thereby, as shown in Fig. 3, a node of second standing wave S2 is present at a position P1 spaced from a center of the region containing top plate 5 and air layer 20 by a distance of A/2, and the node is also present at a position P2 spaced from the center by a distance of B/2.

A node of first standing wave S1 is present at a position P3 spaced by a distance of A/2 from the center of radial waveguide 7a.

Thereby, the phases of standing waves S1 and S2 do not deviate from each other, and thus match with each other. Consequently, standing waves S1 and S2 are mutually coupled more strongly than those in a conventional plasma processing apparatus. Since standing waves S1 and S2 are mutually coupled strongly, standing wave S1 predominantly contributes to formation and maintenance of plasma production region 17 in chamber 1.

The microwave in the TE11 mode is rotated around the axis of waveguide pipe 19, and is transmitted as microwave 21 through waveguide pipe 19 to radial waveguide 7a. Therefore, as shown in Fig. 4, standing wave S1 in radial waveguide 7a rotates in the direction of arrow Y. Thereby, the node and antinode of standing wave S1 are concentric to each other in radial waveguide 7a.

Since the node and antinode of standing wave S1, which is a predominant factor in formation and maintenance of plasma production region 17, are concentric to each other, plasma production region 17 having a substantially concentric plasma density distribution is formed and maintained in chamber 1.

Thus, standing wave S1 formed in radial waveguide 7a of antenna portion 7 predominantly contributes to the formation and maintenance of plasma production region 17 as described above so that antenna portion 7 can control the electromagnetic field, which forms and maintains plasma production region 17.

Thereby, variations in plasma density distribution in plasma production region 17 can be reduced in contrast to a conventional plasma processing apparatus, in which unstable standing wave S2 governs the plasma production region.

Consequently, variations in degree or extent of the plasma processing on the surface of substrate 15 are reduced, and it is possible to improve the uniformity in etching rate, growth rate and others on the surface of substrate 15.

The plasma processing apparatus has been described in connection with the example, in which inner diameter C of chamber 1 is shorter than inner diameter A of radial waveguide 7a. However, the plasma processing apparatus may have inner diameters C and A, which are substantially equal to each other as shown in Fig. 5.

In the plasma processing apparatus shown in Fig. 5, it is considered that plasma production region 17 formed and maintained in chamber 1 hardly changes the value of the composite dielectric constant in the region containing top plate 5 and antenna portion 7. Therefore, standing wave S1 (antenna portion 7) can control plasma production region 17.

If inner diameter C of chamber 1 is longer than inner diameter A of radial waveguide 7a, plasma production region 17 formed and maintained in chamber 1 increases in size, e.g., as shown in Fig. 6.

In this case, it can be considered that the value of the composite dielectric constant in the region containing top plate 5 and antenna portion 7 changes depending on the state of plasma in the plasma production region. Since the value of the composite dielectric constant changes, the value of wavelength λ_g changes, and cannot satisfy the relationship of the foregoing formula so that the mutual coupling between standing waves S1 and S2 cannot be strong. Consequently, it becomes difficult to control the formation and maintenance of plasma production region 17 by standing wave S1 (antenna portion).

According to the plasma processing apparatus of the invention, therefore, the relationship of the foregoing formula is satisfied, and chamber 1 has inner diameter C

substantially equal to or shorter than inner diameter A of radial waveguide 7a. Thereby, antenna portion 17 can control plasma production region 17 so that variations in plasma density are reduced, and uniformity in plasma processing on the surface of substrate 15 can be improved.

Although the present invention has been described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of the present invention being limited only by the terms of the appended claims.

Industrial Applicability

The invention is effectively applied to the plasma processing apparatus, in which the plasma production region formed by supplying the microwave into the chamber effects the predetermined plasma processing such as etching or film deposition on the substrate, and particularly to the structure, in which the electromagnetic field forming the plasma production region is controlled to improve the uniformity in plasma density.